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Nuclear Weapons in a Changing Climate: Probability, Increasing Risks, and Perception

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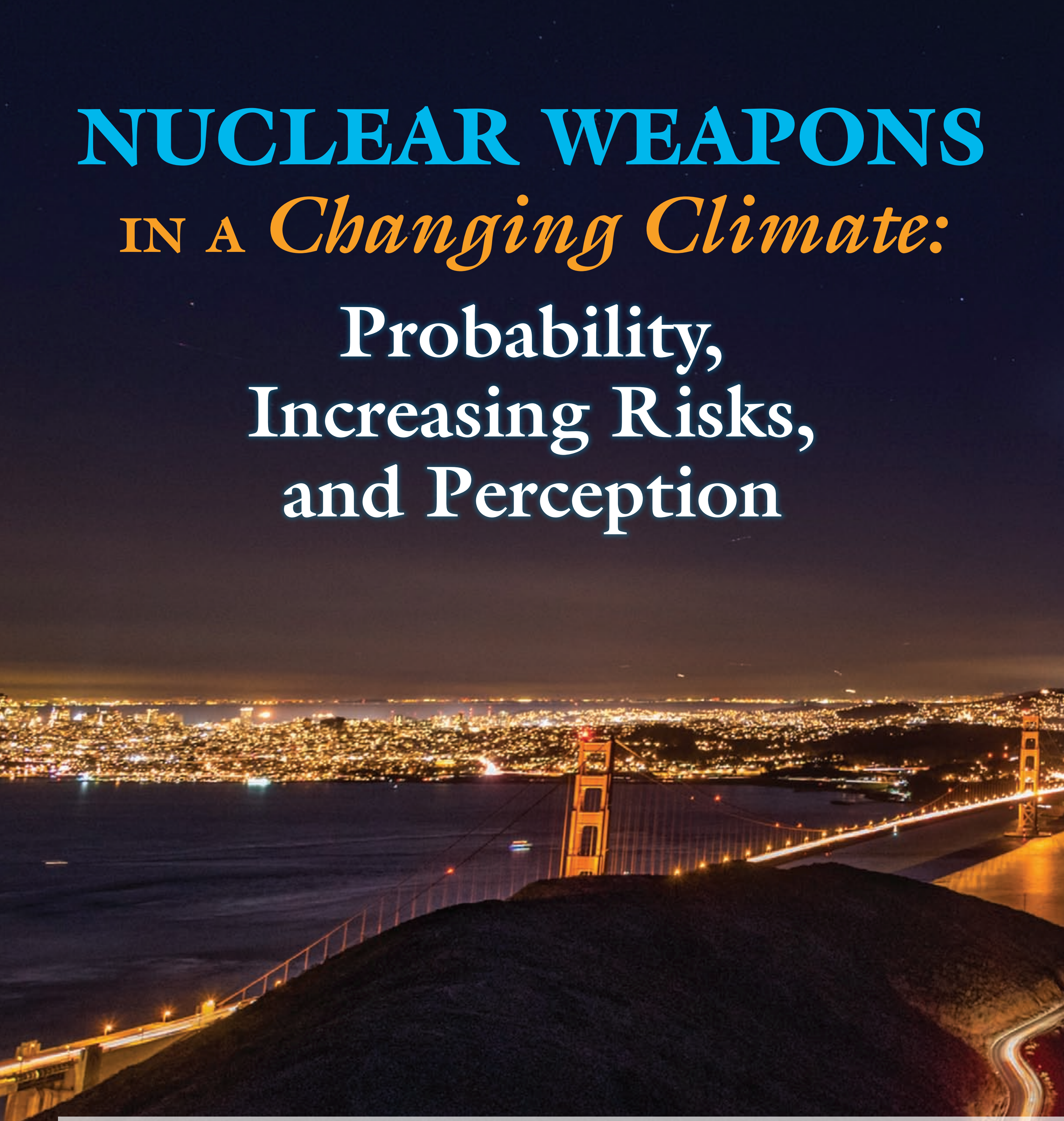

NUCLEAR WEAPONS IN A *Changing Climate:* Probability, Increasing Risks, and Perception

Many people tend to think that the outcome of any nuclear weapons use today will result in an escalatory situation with apocalyptic outcomes for the countries involved.[1] Yet many factors are increasing the probability of the limited use of nuclear weapons (e.g., 1 to 20 warheads) in a range of conflict scenarios. Previous atmospheric model simulations of regional nuclear conflicts employing many relatively small bombs have been estimated to cause a global "nuclear autumn," with great reductions in agricultural productivity, stratospheric ozone loss, and spread of hazardous radioactive fallout.[2] The totality of these effects would result in widespread damage to human well-being and to terrestrial and aquatic ecosystems. In this article, we estimate minimum thresholds for the prevalent types of currently deployed nuclear weapons that would cause equivalent climate impacts, and provide a discussion of the factors that may influence

A nuclear-capable Trident D5 SLBM test over San Francisco on November 7, 2015.

by Adam J. Liska, Tyler R. White, Eric R. Holley, and Robert J. Oglesby

the probability of nuclear weapons use, current risk perception, and possible mitigation actions.

Due to probabilistic realities, Cambridge physicist Stephen Hawking recently concluded that future use of nuclear weapons is highly probable, perhaps even inevitable, given the passage of enough time.[3] Former U.S. Secretary of Defense William Perry also recently warned, "Today, the danger of some sort of nuclear catastrophe is greater than it was during the Cold War."[4] Secretary Perry, speaking about the implications of even a limited nuclear exchange, said, "The political, economic and social consequences are beyond what people understand." Two other former U.S. Secretaries of Defense, Robert McNamara and Graham Allison, and numerous nuclear weapons specialists have also suggested that future use is probable.[5]

In previous regional nuclear war simulations, roughly 100 nuclear explosions with 15-KT (kilotons) TNT yields were estimated to ignite 1,300 square kilometers of urban and other developed land area.[6] The resulting oxidation of carbonaceous materials (e.g., soils, biomass, fossil fuels, asphalt, plastics) was estimated to disperse >5 million metric tons (5 Tg C) of black carbon smoke particles into the stratosphere.[7] Most previous nuclear explosions have not produced significant black carbon emissions because they occurred in the U.S. Southwest desert, on small tropical islands, at high altitudes, or underground.[8]

As a consequence of 5 Tg of black carbon being lofted into the stratosphere, solar radiation on land, atmospheric surface temperature, and rainfall would decrease globally and would likely result in a dramatic decrease in global agricultural production. Agricultural growing seasons could be reduced by 10 to 40 days per year for at least 5 years; global temperatures could be below normal for as long as 25 years; and immediate short-term temperatures could be colder than have occurred in the last 1,000 years.[9] Precipitation could decrease by as much as 20% to 80% in the Asian monsoon region.[10] Large reductions in rainfall would occur in South America and southern Africa, and the American Southwest and Western Australia could be 20% to 60% drier. Climatic changes due to nuclear explosions on developed land could essentially produce a global "nuclear drought," and the resulting famines could kill up to a billion people from starvation, which would probably most affect those communities that are already in food-insecure environments in the developing world, particularly in Sub-Saharan Africa, South Asia, and the Middle East.[11] Significant changes in precipitation would probably also increase conflict in developing regions, although global temperature reductions may reduce social violence in the United States and other developed countries.[12]

Natural systems are also at grave risk, not just local to where the conflagration takes place, but also remotely, and potentially worldwide. Of particular importance are potential consequences for ecosystems and affected biodiversity. Widespread (though low-level) radiation has been reported throughout much of the Pacific basin several years after the Fukushima disaster in March 2011, which implies that radiation and other pollutants due to even a limited nuclear strike could be similarly dispersed.[13] The spread of toxic radionuclides and their long-term effects would also be greatly magnified if a nuclear reactor, a nuclear power plant, or a nuclear weapons stockpile were to be targeted in any potential nuclear conflict, with the latter being the most likely set of targets out of the three.[14] In 2016, former Japanese Prime Minister Naoto Kan said that had the Fukushima nuclear power plant melted down further, the spread of radiation could have been worse than the Chernobyl disaster, and he stated, "The future existence of Japan as a whole was at stake."[15]

Due to irreversible physical processes described by the second law of

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Anti-nuclear occupy tent protest against the Japanese government in Tokyo, Japan, on May 8, 2015.

Table 1. Nuclear Weapons Stockpiles and Types by Country in 2016: Test Dates,[28] and Number Deployed, Reserve, and Total,[29] as Strategic and Tactical[30]

Country	First Nuclear Test	Deployed	Reserve	Strategic	Tactical	Total Stockpile
United States	1945	1,590	2,260	2,600	860–1,040	6,800
Russia	1949	1,790	2,700	2,152	825	7,000
United Kingdom	1952	120	95	215	0	215
France	1960	280	10	200	80	300
China	1964	0	260	260	0	260
India	1974	0	110–120	110–120	0	110–120
Pakistan	1998	0	120–130	120–130	Upgrading	120–130
Israel	—	0	80	Unknown	Unknown	80
North Korea	2006	0	4–20	4–20	0	4–20

thermodynamics, complex patterns in physical systems are less probable than disordered systems consisting of smaller molecules and random atomic motion, which is why complex dynamic structures have limited lifetimes and disintegrate and diffuse when energy becomes limited, and why continual energy use is needed to reproduce or recreate them and work against the tendency toward disorder and increasing entropy.[16] Because of these physical principles, "it's always a lot easier to and quicker to destroy something than it is to build it," which is why risk analysts are always preparing for the next catastrophe, with potential nuclear events being perhaps the most cataclysmic.[17]

Potential for Future Limited Use of Nuclear Weapons

Jeffrey Larson, Director of Research at the NATO Defense College, recently defined "limited nuclear war" as "a conflict in which nuclear weapons are used in small numbers and in a constrained manner in pursuit of limited objectives (or are introduced by a country or non-state actor in the face of conventional defeat)."[18] Limited use of nuclear weapons by either the United States or other nuclear actors is seen by U.S. military strategists as possible to occur, either as demonstrations to signal willingness to escalate conflicts; to achieve conflict termination if the United States or an ally is in serious military jeopardy; as retaliation for a chemical or biological weapons attack (or substantial cyberattack or nuclear terrorist attack); or to secure a nuclear state that has lost control of its weapons, among other possible scenarios; many of these situations could lead to use of nuclear weapons on noncivilian targets.[19] There are also concerns that greater accuracy in warhead delivery coupled with lower yield weapons produced in nuclear modernization programs may lower the threshold for future nuclear weapons use.[20] In evaluating the emerging nuclear landscape in 2014, James J. Wirtz, the Dean of the U.S. Naval Postgraduate School, stated, "Emerging nuclear powers exhibit clear indications that they do in fact see great utility in nuclear deterrence to include interest in the strategic and tactical use of their nuclear arsenals to achieve their security objectives."[21] Former U.S. Secretary of Defense Robert McNamara, who participated in the Cuban Missile Crisis of 1962, had repeatedly emphasized that humans and politicians are not always rational, and our indefinite capacity for fallibility increases the probability of nuclear weapons use, given their widespread deployment.[22] Many observers today are concerned that nuclear actors may fumble into circumstances, or make "miscalculations," where these weapons are used.[23]

Nuclear policy analysts have found recent troubling developments in the policies of Russia, Pakistan, and India concerning the first use of nuclear weapons. Many analysts agree that the shifting nuclear force postures and doctrines of these states makes a limited nuclear exchange much more probable to occur. Pakistan and India have come close to a regional nuclear exchange three times in recent decades.[24] Paul Bernstein at the National Defense University in Washington, D.C., stated, "Pakistan's nuclear doctrine, while officially still described as 'credible minimum deterrence,' in fact has evolved toward one reliant on the early first use of nuclear weapons."[25] Russian President Vladimir Putin recently announced his country's intentions to "strengthen the military potential of strategic nuclear forces," specifically the ability of Russian missiles to penetrate any defense system.[26] Bernstein also stated, "It is clear that Russian nuclear strategy today encompasses a concept for deterring and terminating conventional war based on the threat of limited nuclear strikes for the purposes of 'demonstration' and 'de-escalation.'"[27] Despite great reductions in nuclear weapon stockpiles by the United States and Russia since the 1980s, now nine countries have nuclear weapons programs, most with bombs significantly larger than those used at Hiroshima and Nagasaki, Japan, in 1945 (Table 1).

Table 2. Major Types of Deployed Nuclear Weapons in 2014 by Delivery System, With Explosive Yields and the Equivalent Number of Bombs Needed To Ignite 1,300 Square Kilometers (~5 Tg C Emission)[35]

Bomb Type (Deployed Warheads, Number)	Country	Yield, KT	Burn Radius, km	Burned Area, km²	Equivalent Number	Total Yield, KT
Air-dropped						
Hiroshima	United States	15	2.0	13	100	1,500
B61-12 (in production)	United States	50	3.2	32	40.3	2,016
DH-10 ALCM (150)	China	90	4.1	52	25.2	2,267
ALCM (78)	United States	150	5.0	78	16.7	2,511
B61-3/-4 (184)	United States	170	5.2	86	15.1	2,575
AS-15A/B ALCM (72)	Russia	200	5.6	98	13.3	2,660
Rafale C/M F3 (50)	France	300	6.6	135	9.6	2,884
B61-7/11, B83-1 (11)	United States	1,200	11.4	410	3.2	3,806
SLBM						
Mk-4/4A, 4x (660)	United States	100	4.2	56	23.2	2,315
Trident II D5, 3x (48)	United Kingdom	100	4.2	56	23.2	2,315
M45/M51, 4x (48)	France	100	4.2	56	23.2	2,315
RSM-54/56, 4x (144)	Russia	100	4.2	56	23.2	2,315
JL-1/2 (48)	China	300	6.6	135	9.6	2,884
Mk-5, 4x (300)	United States	475	7.9	195	6.7	3,162
ICBM						
Mk-21 (250)	United States	300	6.6	135	9.6	2,884
Mk-12A, 3x (220)	United States	335	6.9	148	8.8	2,949
RS-12M2/12M (177)	Russia	800	9.7	296	4.4	3,510
Land-based missiles						
DF-21 (<100)	China	300	6.6	135	9.6	2,884
DF-3A/4 (10)	China	3,300	17.1	921	1.4	4,660
DF-5A (20)	China	5,000	20.2	1,284	1.0	5,063

Note. The approximate relationship of the radius of the area burned relative to blast yield, $R_{km} = 0.67\,(KT)^{0.4}$, was calibrated to the firestorm at Hiroshima.[36] All bomb yields and numbers deployed, unless noted:[37] B61-12;[38] Russian and Chinese ALCM yields.[39] Where bombs were noted to have variable yields, the highest yields are shown; multiple warheads on single delivery vehicles are designated with "x." Total yield is equivalent number multiplied by individual yields.

Nuclear Drought: Minimum Thresholds for Nuclear Weapons Use and Carbon Sources

Many currently deployed nuclear weapons, such as air-launched cruise missiles (ALCM), submarine-launched ballistic missiles (SLBM), intercontinental ballistic missiles (ICBM), air-dropped bombs, and land-based missiles, have explosive yields of 90 KT to 5 megatons (MT), which are 6 to 330 times more powerful than those employed in previous atmospheric model simulations that primarily assumed multiple 15-KT explosions (Table 2). The use of only one 5-MT land-based missile deployed by China could burn an area similar in size to that of one hundred 15-KT explosions. Alternatively, if the United States dropped only three 1.2-MT bombs, or used two Trident D5 SLBM (each with four 475-KT warheads), the size of the explosions would exceed the land area required to produce similar climate impacts. Use of only four 800-KT Russian ICBMs or ten 300-KT French gravity bombs would also have similar climate impacts. Thus, use of as few as 1 to 10 deployed nuclear weapons, and fewer than 25 of these prevalent types, from the five official nuclear weapons countries could produce a nuclear drought; many of the most prevalent types of strategic nuclear weapons deployed by these countries are shown (Table 2). For these five coun-

Kuwaiti oil fields burning after the Gulf War in 1991.

tries in total, there are roughly 1,682 warheads deployed that have yields between 100 and 300 KT; ~697 warheads with yields between >300 and 800 KT; and ~41 warheads with yields between 1 and 5 MT. Furthermore, the use of smaller bombs by any actor could easily escalate into the use of larger weapons, such as any of the major types that are deployed and shown here, although new U.S. policy suggests the response to any adversarial use of nuclear weapons would elicit a "proportional" nuclear response by the United States.[31] Nuclear drought events could also occur by regional nuclear exchanges between Pakistan and India (~6.6 Tg C), North Korea or Russia and the United States, or Israel and Iran, among many other possible increasing numbers of combinations.[32]

Vegetation is not required to produce significant climate impacts. Even in the desert Middle East, a single high-temperature nuclear explosion (e.g., 3,000–7,700°C) could ignite aboveground oil reserves, infrastructures, and wellheads, and produce significant stratospheric particle dispersion.[33] A nuclear explosion could create greater climate impacts than the Kuwaiti oil field fires of 1991 due to higher altitude smoke dispersion into the stratosphere and more wellheads potentially being ignited. During the Gulf War in 1991, Kuwaiti oil wells were set on fire in January and some burned until November, when they were actively extinguished. At a rate of ~3,400 metric tons of soot emitted per day for approximately 6 months, ~0.6 Tg of black carbon was dispersed into the troposphere from 610 ignited wells.[34]

Climate Change, Nuclear Energy, and Nuclear Weapons

Many developed and developing countries (i.e., China, India, Pakistan, Turkey, Egypt, Saudi Arabia, United Arab Emirates, Jordan, and Russia, among others) are expanding or plan to expand their nuclear energy sectors.[40] As a source of energy for development and to mitigate anthropogenic climate change, the global expansion of nuclear energy is recognized by many observers to also increase the probability of future nuclear weapons events.[41]

In 2016, North Korea conducted two nuclear weapons tests and related missile tests showing that the country is developing advanced capabilities. North Korea's September 9, 2016, nuclear test was the 2,056th nuclear test conducted since 1945 by one of eight countries.[42] On January 27, 2017, satellite photos indicated that North Korea had also resumed plutonium production at the Yongbyon nuclear reactor, which had produced fuel for its previous nuclear tests.[43] With associated spent fuel reprocessing, the Yongbyon facility can produce ~6 kg per year of weapons-grade plutonium (>93% plutonium-239), enough for roughly one bomb per year.[44] Yongbyon is one of 16 significant reprocessing facilities globally; each country with a nuclear weapons program has at least one facility.[45] Iran also has many reasons to want a nuclear weapons program, including developing a deterrent against its two main rivals, the United States and Israel, both nuclear powers. Iran has key nuclear facilities in Arak, Bushehr, Natanz, Qom, and Parchin to enrich uranium and dramatically shorten the time to "break out" the production of nuclear weapons. Iran has also invested in developing new missiles that analysts believe can carry a nuclear payload.[46]

Further nuclear threats include terrorists obtaining fissile materials from either existing official nuclear weapons states (United States, Russia, United Kingdom, France, China) or unofficial countries (India, Pakistan, Israel, North Korea) or from any of the 450 nuclear power facilities operating in 30 countries globally.[47] To prevent nuclear terrorism from occurring, governments have primarily sought to secure all fissile nuclear materials internationally.[48]

These existing and increasing nuclear threats will be further impacted by fossil-fueled anthropogenic climate change, which will increase the probability of future conflicts.[49] Over the long term, potential sea-level rise by 4 to >6 meters by 2100 could result in more than a billion migrants, which could also exacerbate global conflicts.[50] Escalation of conflicts to limited nuclear confrontations could result from any or all of these factors, especially given enough time for such events to occur.

Missiles paraded in North Korea to celebrate the 105th birthday of Kim Il Sung in Pyongyang, April 15, 2017.

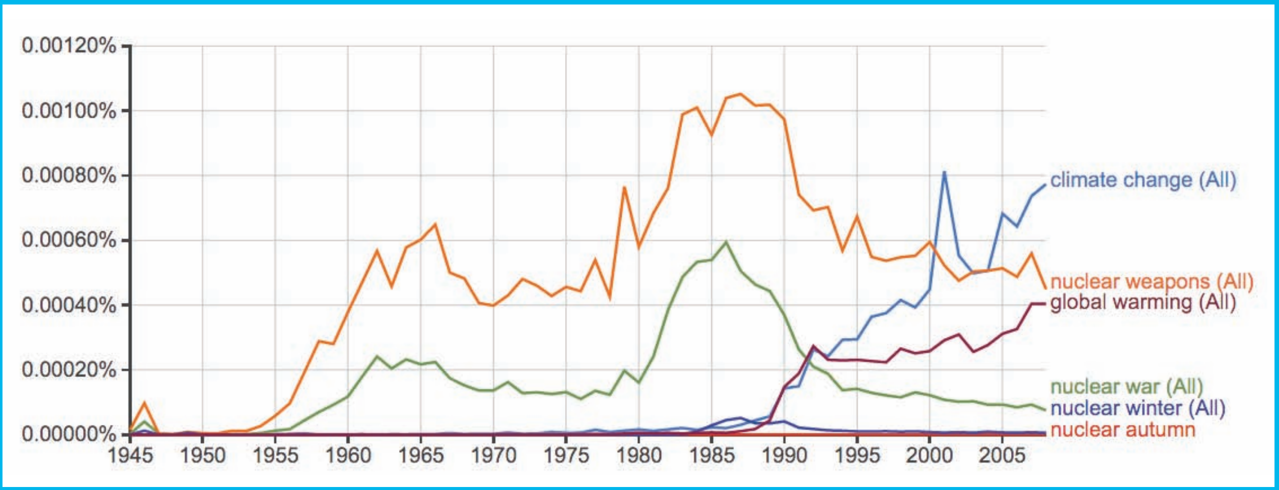
Risk Assessment, Perception, and Ethical Considerations

One measure of the relative attention given to critical environmental issues over time is the frequency of words occurring in published books. The relative frequency of "nuclear war" and "nuclear weapons" peaked in English books in 1986 and 1987, respectively (Figure 1). "Climate change" became a relatively dominant term beginning in 2001, with "global warming" being less prevalent. "Nuclear winter" also peaked in 1987, and "nuclear autumn" has been used even less, with both terms occurring at least 80 times less frequently than "climate change" by 2008. Due to the relative prevalence of "nuclear weapons" since the 1960s, emphasis on these issues is likely to continue. Such language terms are also imprecise and vague, and could describe a multitude of phenom-

Wikimedia Commons/US Department of Defense

A 21 KT nuclear explosion with battleships for size reference at Bikini Atoll, July 25,1946. The world's largest nuclear bomb deployed today by China (5 MT) is 238 times larger and could ignite ~1280 square kilometers of land.

Figure 1. Nuclear weapons "on our minds": The relative frequency of nuclear weapons and climate change issues in English books, 1945–2008.



Source: Google Books Ngram Viewer, http://books.google.com/ngrams.

ena, which is why such terms need to be accompanied by specific numbers and further qualifying descriptors to be meaningful.[51]

A multitude of changing forces have shaped public discourse on diverse environmental topics over the last century.[52] Most environmental politics have tended to approach problems on regional scales due to local political power dynamics, which may have limited concern for nuclear climate impacts that would occur on a global scale.[53] Yet in 2017, the World Economic Forum recognized weapons of mass destruction (WMDs, which primarily include nuclear weapons) to be the largest potential negative impact for the global economy out of all major threats in the next 10 years.[54] Past trends also reflect the nature of nuclear weapons as fast-acting and immediate risks relative to climate change concerns, which have been seen by many as more of a long-term issue. But even to limit temperature increases to 2°C, projections of carbon emissions under the 2016 Paris Agreement would still require undeveloped and optimistic negative emissions technology to be employed at scale by ~2030, suggesting the immense magnitude of the task posed to mitigate the destructive effects of anthropogenic climate change, and explaining why nuclear energy may be more prevalent in the future as a reduced-emissions energy source.[55]

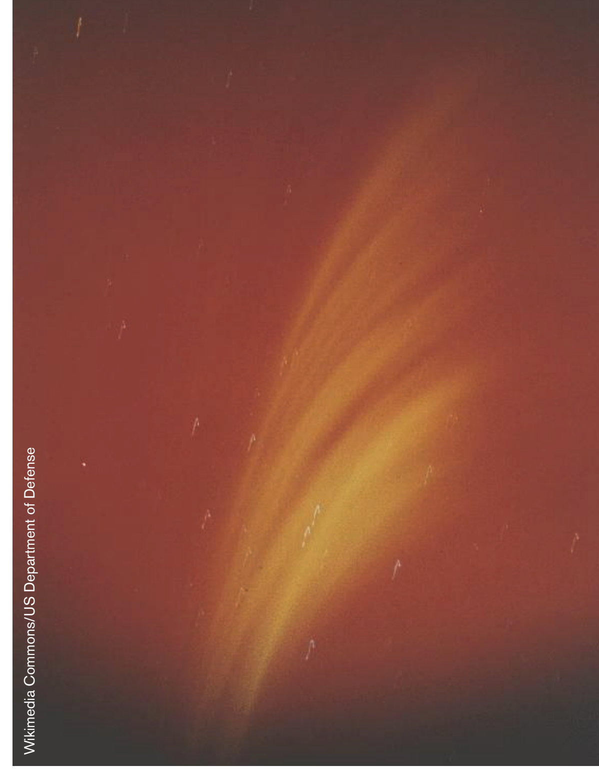
As a result of recent developments in nuclear weapons, nuclear energy, and climate change, the Doomsday Clock was set 2 minutes closer to midnight in 2015, and in 2017 the clock moved 30 seconds closer, to 2½ minutes to midnight, due to global political developments; this is the closest to midnight since 1953, after the United States and Russia first tested thermonuclear bombs.[56] Despite ominous risk assessments from the World Economic Forum, the Doomsday Clock, and many others discussed in the preceding, social incentives interfere with our risk perception, in addition to prevalent psychological tendencies that also cause us to underestimate risks.[57] The philosopher of science Karl Popper similarly warned of our narrow perspectives: "Our own ways of life are still beset by taboos; food taboos, taboos of politeness, and many others."[58] Financial incentives can also interfere with scientific judgment, as recently elaborated by the U.S. National Academy of Sciences: "Judges and juries, however, must consider financial conflicts of interest when assessing scientific testimony. The threshold for pursuing the possibility of bias must be low. In some instances, judges have been frustrated in identifying expert witnesses who are free of conflict of interest because entire fields of science seem to be co-opted by payments from industry."[59] Institutional incentives on science have also recently been asserted to limit the identification of true novel relationships, as opposed to the repeated production of false positives.[60] Corporate executives also recognize powerful internal and external forces that can undermine business performance and increase unnecessary risks.[61]

Beyond the social and institutional issues, the values behind our actions are also defined by philosophy and religion. Our moral responses to the threats of nuclear weapons, or to any ethical issue, evolve as the result of complex moral reasoning, interpretation, and our personal histories.[62] Ethical dilemmas such as determining the "best" approach to the problems of nuclear weapons, unfortunately, will not be resolved by recourse to facts alone, nor can any final moral conclusions be obtained by philosophy.[63] Despite such uncertainty, any management of nuclear weapons should clearly try to minimize harm to civilian populations to the highest degree possible; however, even the indirect climate effects of limited use of nuclear weapons on noncivilian targets may still be able to kill a billion people.

When considering the immense risks to global human well-being posed by the climate effects of limited nuclear weapons use and the associated spread of toxic radionuclides, it appears entirely appropriate to reflect on the massively devastating and nearly continuous wars of global history; perhaps we should not be overly optimistic and rely too much on the notion that "this time is different."[64] Where we do not act due to our conflicting obligations, where is the threshold that identifies us as bystanders to the grand perils of nuclear weapons use?[65] All of these social, cultural, and ethical factors have the potential to create biased evaluations and influence our perceptions and actions concerning the climate change risks and other hazards from nuclear weapons.

Nuclear Weapons in Transition

As the climate implications of the limited use of nuclear weapons become more widely recognized and better characterized, specialized nuclear weapons, such as electromagnetic pulse (EMP) devices that are detonated at an altitude of >25 km, may become preferable alternatives that would not oxidize terrestrial carbon but could still serve strategic objectives.[66] When detonated, an EMP device ionizes atmospheric molecules and creates a massive surge of free electrons that can overload electrical systems and cause widespread failures, thus disrupting the ionosphere, as opposed to the biosphere. In 1962, a U.S. EMP test with a 1.4-MT nuclear explosion at an altitude of ~400 km above sea level unexpectedly caused streetlights to burn out and a communications system failure in Honolulu, Hawaii, which was ~1,100 km from the epicenter of the blast.[67] Most electrical systems across a broad area under such an EMP explosion would become nonfunctional; the blast would only harm people who are directly dependent on electrical devices for survival, but the global climate implications from the use of conventional nuclear weapons would be averted. Uses of EMP devices have been widely discussed as probable strategic applications of nuclear weapons, although their possible exclusive use instead of conventional bombs has received less attention.[68]



An electromagnetic pulse created by a 1.4 MT atmospheric nuclear explosion at an altitude of 400 km.

In summary, as long as conventional nuclear weapons are prevalent, the breadth of existing research indicates that the question is not whether a nuclear drought can occur, but what factors increase its probability of occurring and what actions can be taken to mitigate the potentially devastating global impacts. Even in the 1950s, John von Neumann, Princeton professor of mathematical physics, creator of game theory, and a major designer of the modern computer (which was used primarily for nuclear weapons development), thought "atomic war was almost certainly unavoidable"—a conclusion that Stephen Hawking echoes today.[69] Is sufficient action being taken today to avoid the limited use of nuclear weapons in the future and avert the potential for devastating climate impacts and the associated spread of toxic radionuclides? Accumulated research is already specific enough to provide adequate incentives to approach the problem of nuclear drought with a new urgency. The storage of nuclear spent fuel rods in vulnerable facilities also needs greater attention, as the Fuku-

Nuclear ballistic missiles on parade in Moscow, May 2014.


Wikimedia Commons/US Department of Defense

Atmospheric particle dispersion from a 10 MT nuclear bomb test, 'Ivy Mike', October 31, 1952.

shima disaster dramatically showed. More research is needed for a better understanding of the probability of nuclear weapon events and to foster more adequate responses and alternative solutions to these serious global challenges for a future sustainable environment.

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Atmospheric particle dispersion from a 15 KT nuclear artillery shell test in Nevada, May 25, 1953.

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